Hydrogeologic Framework of the Floridan Aquifer System in Florida and in Parts of Georgia, Alabama, and South Carolina

By JAMES A. MILLER

REGIONAL AQUIFER-SYSTEM ANALYSIS

U.S. GEOLOGICAL SURVEY PROFESSIONAL PAPER 1403–B

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON: 1986

Excerpt: PP 1403-B Hydrogeologic Framework of the Floridan Aquifer System in Florida and in Parts of Georgia, Alabama, and South Carolina

about 13,000 ft^2/d (Ryder, 1982). Hawthorn limestone beds that are local aquifers yield up to 750 gal/min (Boggess, 1974).

FLORIDAN AQUIFER SYSTEM

GENERAL

The Floridan aquifer system is a thick sequence of carbonate rocks generally referred to in the literature as the "Floridan aquifer" in Florida and the "principal artesian aquifer" in Georgia, Alabama, and South Carolina. As defined in this report, the Floridan aquifer system encompasses more of the geologic section and extends over a wider geographic area than either the Floridan or the principal artesian aquifer, as those aquifers have been described in the literature. Figure 7 shows the geologic formations in Florida and southeastern Georgia that were called "principal artesian formations" by Stringfield (1936), those that were included in the "Floridan aquifer" as defined by Parker and others (1955), and those placed in the "principal artesian aquifer" as defined by Stringfield (1966). Subsequent deep drilling and hydraulic testing have shown that highly permeable carbonate rocks extend to deeper stratigraphic horizons than those included in either the "Floridan" or "principal artesian" aquifers as originally described. Accordingly, this author (cited by Franks, 1982) extended the base of the Floridan aquifer downward to include part of the upper Cedar Keys Limestone (fig. 7). Limestone and dolomite beds that commonly occur at the base of the Hawthorn Formation have been included as part of the "Floridan" or "principal artesian" aquifer in most previous reports. However, data collected for the present study show that, except very locally, there are no high-permeability carbonate rocks in the lower part of the Hawthorn Formation that are in direct hydraulic contact with the main body of the Floridan aquifer system.

The Hawthorn Formation was thus excluded from the aquifer system in a report by Miller (1982a) that was one of a series of several interim reports published during the present study. In these interim reports, the aquifer system was called the "Tertiary limestone aquifer system of the Southeastern United States." This cumbersome, albeit more accurate, terminology has subsequently been abandoned, and the aquifer system is referred to in this professional paper as the "Floridan aquifer system" (see Johnston and Bush, 1985 for a more detailed history of the terminology applied to the aquifer system).

The Floridan aquifer system is defined in this report

EPOCH		Stringfield (1936) Formation	Stringfield (1936) Aquifer	Parker and others (1955) Formation	Parker and others (1955) Aquifer	Stringfield (1966) Formation	Stringfield (1966) Aquifer	Miller, in Franks (1982) Formation	Miller, in Franks (1982) Aquifer	Miller (1982 a,c) Formation	Miller (1982 a,c) Aquifer system	This Report Formation	This Report Aquifer system
MIOCENE	Middle	Hawthorn Formation		Hawthorn Formation		Hawthorn Formation		Hawthorn Formation		Hawthorn Formation		Hawthorn Formation	
MIOCENE	Early	Tampa Limestone	Principal artesian formations	Tampa Limestone	Where Permeable	Tampa Limestone	Principal artesian aquifer	Tampa Limestone	Where Permeable	Tampa Limestone	Where Permeable	Tampa Limestone	Where Permeable
OLIGOCENE		Oligocene Limestone	Principal artesian formations	Suwannee Limestone	Floridan aquifer	Suwannee Limestone	Principal artesian aquifer	Suwannee Limestone	Floridan aquifer	Suwannee Limestone	Tertiary limestone aquifer system	Suwannee Limestone	Floridan aquifer system
EOCENE	Late	Ocala Limestone	Principal artesian formations	Ocala Limestone	Floridan aquifer	Ocala Limestone	Principal artesian aquifer	Ocala Limestone	Floridan aquifer	Ocala Limestone	Tertiary limestone aquifer system	Ocala Limestone	Floridan aquifer system
EOCENE	Middle			Avon Park Limestone; Lake City Limestone	Floridan aquifer	Avon Park Limestone; Lake City Limestone	Principal artesian aquifer	Avon Park-Lake City Limestones	Floridan aquifer	Avon Park-Lake City Limestones	Tertiary limestone aquifer system	Avon Park Formation	Floridan aquifer system
EOCENE	Early					Oldsmar Limestone	Principal artesian aquifer	Oldsmar Limestone	Floridan aquifer	Oldsmar Limestone	Tertiary limestone aquifer system	Oldsmar Formation	Floridan aquifer system
PALEOCENE								Cedar Keys Limestone		Cedar Keys Limestone		Cedar Keys Formation	

Figure 7. Comparison of aquifer terminologies.

as a vertically continuous sequence of carbonate rocks of generally high permeability that are mostly of middle and late Tertiary age and hydraulically connected in varying degrees and whose permeability is, in general, an order to several orders of magnitude greater than that of those rocks that bound the system above and below. As plate 2 shows, the Floridan aquifer system includes units of late Paleocene to early Miocene age. Very locally, in the Brunswick, Ga., area, the entire Paleocene section plus a thick sequence of rocks of Late Cretaceous age are part of the aquifer system. In and just downdip of the area where the aquifer system crops out, the entire system consists of one vertically continuous permeable unit. Farther downdip, less permeable carbonate units of subregional extent separate the system into two aquifers, herein called the Upper and Lower Floridan aquifers (fig. 8). These less permeable units may be very leaky to virtually nonleaky, depending on the lithologic character of the rock comprising the unit. Because they lie at considerable depth, the hydrologic character and the importance of the subregional low-permeability units are known from only a few scattered deep test wells. Local low-permeability zones may occur within either the Upper or the Lower Floridan aquifer. In places (for example, southeastern Florida), low-permeability rocks account for slightly more than half of the rocks included in the aquifer system.

Even though the rocks that comprise the base of the Upper Floridan aquifer are not everywhere at the same altitude or geologic horizon or of the same rock type, the presence of a middle confining unit over about two-thirds of the study area has led to a conceptual model for the Floridan aquifer system that consists of two active permeable zones (the Upper and Lower Floridan aquifers) separated by a zone of low permeability (a middle confining unit). Because of this simplified layering scheme, it is necessary to greatly generalize the highly complex sequence of high- and low-permeability rocks that comprise the aquifer system. Local confining beds (see, for example, cross section E-E', pl. 21) are either disregarded because they are regionally unimportant or lumped with one of the major layers. The purpose of the conceptual model, and of the digital computer model derived from it and described by Bush and Johnston (1985) is to portray the major aspects of ground-water flow within the Floridan aquifer system. In like manner, the descrip-

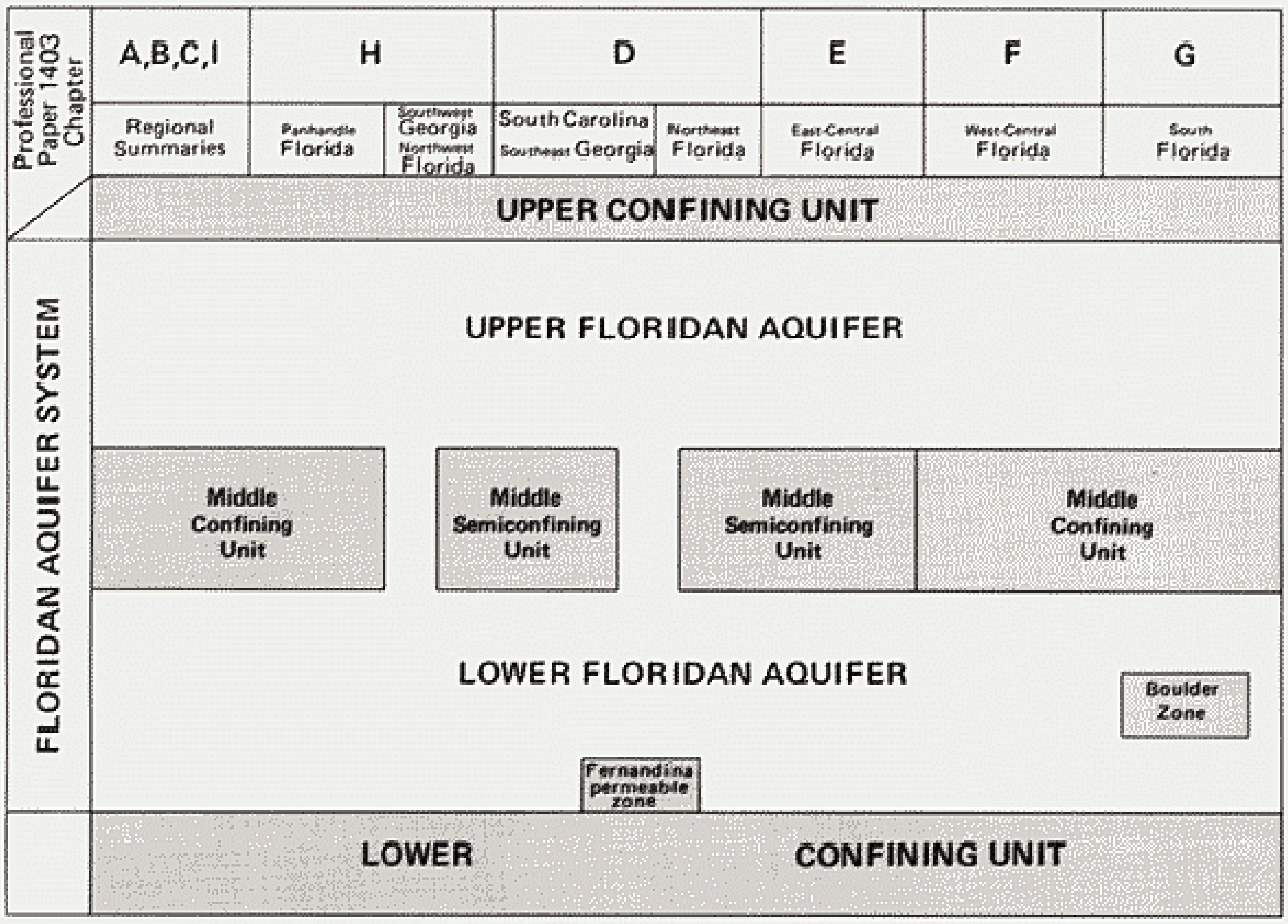


Figure 8. Aquifers and confining units of the Floridan aquifer system.

tion of the aquifer system's geohydrologic framework in this report is intended to show the principal variations in permeability within the aquifer system. In both cases, local anomalies that do not fit with overall (regional) conditions are ignored.

Regionally, the top of the Floridan aquifer system in most places lies at the top of rocks of Oligocene age (Suwannee Limestone) where these strata are preserved. Where Oligocene rocks are absent, the aquifer system's top is generally at the top of upper Eocene rocks (Ocala Limestone). Locally, in eastern panhandle Florida and in west-central peninsular Florida, rocks of early Miocene age (Tampa Limestone) are highly permeable and hydraulically connected to the aquifer system. In places, upper Eocene through lower Miocene rocks are either missing owing to erosion or nondeposition or of low permeability; at these places, rocks of middle Eocene age (Avon Park Formation) mark the top of the aquifer system. It is important to note that there are some places where the upper part of a given formation that comprises the top of the aquifer system consists of low-permeability rocks. At such places, the low-permeability beds are excluded from the aquifer system, and the top of the system is considered to be the top of the uppermost high-permeability carbonate rock. The top of the system, then, may lie within a stratigraphic unit rather than at its top. Because the permeability contrast between the aquifer system and its upper confining unit does not everywhere follow stratigraphic horizons, neither does the top of the aquifer system. Likewise, the top of the aquifer system may locally lie within a limestone unit if the upper part of the limestone consists of low-permeability rock and the lower part is highly permeable.

The time-stratigraphic units or parts of units that mark the top of the Floridan aquifer system at selected localities are shown in figure 9, as well as the time-rock units that comprise the Upper and Lower Floridan aquifers and the units that are considered to represent the aquifer system's base. Figure 9 shows a series of idealized chronostratigraphic columns compiled from well data at several locations in the study area, along with the permeability characteristics of each chronostratigraphic unit at each location. Examination of this figure shows that, in addition to the variations in the top and base of the aquifer system, the degree of complexity varies greatly within the system. Generally speaking (and as figure 9 shows), the aquifer system in most places can be divided into an Upper and Lower Floridan aquifer separated by less-permeable rock. In places, however, no middle confining unit exists (for example, the Baxley, Ga., and Gainesville, Fla., columns on fig. 9), and the aquifer system is highly permeable throughout its vertical extent. In other places, thick sequences of low-permeability rock occur at several levels within the aquifer system (for example, the Savannah, Ga., and West Palm Beach, Fla., areas in fig. 9), and the several discrete permeable zones of the system may be hydraulically separated.

Regionally, and in a fashion similar to the way in which the top is defined, the base of the aquifer system is defined as the level below which there is no high-permeability carbonate rock. The base of the system is generally either (1) glauconitic, calcareous, argillaceous to arenaceous rock that ranges in age from late Eocene to late Paleocene (fig. 9) or (2) massively bedded anhydrite that commonly occurs in the lower two-thirds of the Paleocene Cedar Keys Formation. Locally, near Brunswick, Ga., micritic limestone and argillaceous limestone of Late Cretaceous (Tayloran) age mark the base of the aquifer system. The permeability of the micritic and argillaceous carbonate rocks, the anhydrite beds, and the various clastic rocks that comprise the base of the system is much less than that of the carbonate rocks above. Regardless of its lithologic character, the lower confining unit, whose top is mapped in this report as the base of the aquifer system, everywhere separates the system from deeper, predominantly clastic aquifers of early Tertiary and Late Cretaceous age.

The upper confining unit of the Floridan aquifer system generally consists of rocks of middle and late Miocene age. Where older rocks such as the lower Miocene Tampa or Oligocene Suwannee Limestones are of low permeability, they are also included in the upper confining unit. In parts of the study area, the upper confining unit has been removed by erosion and the aquifer system either: crops out, is covered by only a surficial sand aquifer, or is covered very locally by clayey residuum. Hydraulic conditions within the aquifer system accordingly vary from confined to unconfined. Where thick sequences of less permeable rocks of subregional extent are present within the aquifer system, they divide it into two major aquifers. The uppermost aquifer (Upper Floridan) generally consists of rocks of Oligocene, late Eocene, and late middle Eocene age (fig. 9). The lower aquifer (Lower Floridan) generally consists of rocks of early middle Eocene to late Paleocene age. Where no middle confining unit separates the two aquifers, all the permeable rock comprising the aquifer system is referred to as the Upper Floridan aquifer. The middle confining unit separating the Upper and Lower Floridan aquifers is generally found in the middle part of rocks of middle Eocene age. The less permeable material that comprises the middle confining unit, however, is not everywhere of the same age (fig. 9), nor does it everywhere consist of the same rock type, as a later section of this report discusses in detail.

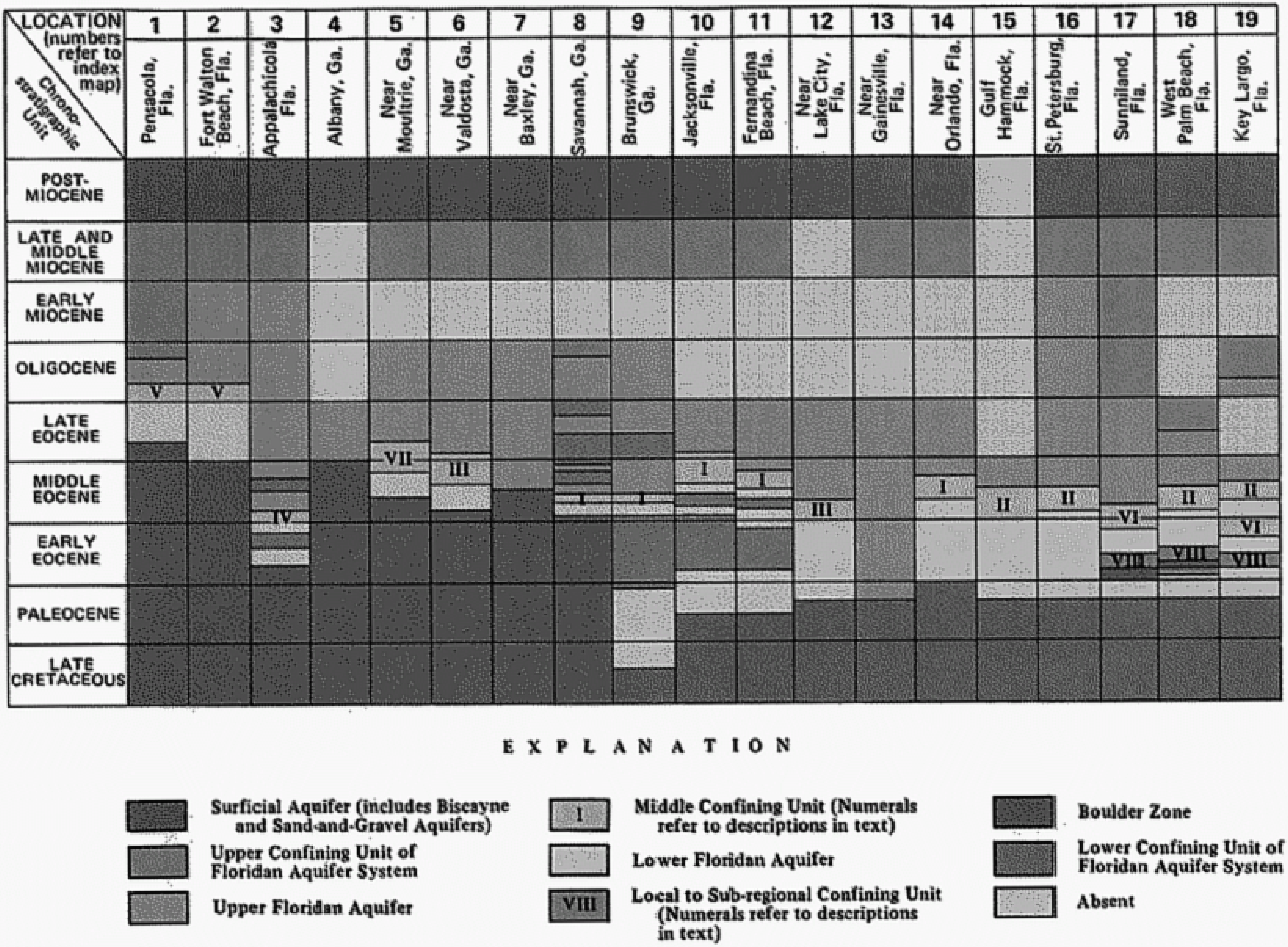


Figure 9. Relation of time-stratigraphic units to the Floridan aquifer system, its component aquifers, and its confining units.

Throughout much of the study area, the water in the Lower Floridan is brackish to saline. The Lower Floridan is moderately to highly porous, and digital simulation indicates that it transmits water sluggishly (see Bush and Johnston, 1985). Little is known about the Lower Floridan aquifer because in most places there is no reason to drill into a deep aquifer containing poor-quality water when an adequate shallower source of good-quality water (the Upper Floridan aquifer) exists.

Local to subregional zones of cavernous permeability occur at several levels within the Floridan aquifer system. The best known of these zones, called the "Boulder Zone" (Kohout, 1965) because of its difficult drilling characteristics, is found in the lower part of rocks of early Eocene age (fig. 9) in southern Florida. Borehole televiewer surveys show that this zone consists of a series of thin to moderately thick horizontal openings connected vertically by fractures, some of which have been opened and enlarged into vertical tubes by solution. The Boulder Zone resembles modern cave systems and is presumed to have formed in a similar fashion—by solution at or above an early Eocene paleowater table. As a result, the transmissivity of the Boulder Zone is extremely high (Meyer, 1974). Other shallower, less extensive cavernous zones are found farther north in the Florida peninsula (Miller, 1979). Where these cavernous zones are developed in the parts of the aquifer system that contain saline water, they are used as receiving zones for underground injection of treated sewage and other industrial wastes.

Within the sequence of rocks that is here treated as an upper confining unit are permeable zones that extend over part of a county or over several counties and that are important local sources of water. These localized artesian aquifers are considered in this report to comprise part of the upper confining unit of the Floridan aquifer system because their permeability is low in comparison with that of the Floridan and because they are of limited extent.

EXTENT

The Floridan aquifer system becomes thin in updip areas where it is interbedded with clastic rocks. The limestones that comprise the aquifer system grade in an updip direction into sandy or argillaceous limestone, which in turn grades into calcareous sand or clay. Still farther updip, these calcareous clastic rocks grade into fully clastic sediments that are stratigraphically equivalent to the aquifer system but are much less permeable than their limestone equivalents. The updip facies change from limestone into clastic rocks and the corresponding decrease in the amount of highly permeable rock in an updip direction are shown by geohydrologic cross-sections A-A', B-B', C-C', D-D' and O'-O'' (pl. 15, 16, 18, 19, 20). The updip limit of the Floridan aquifer system (plate 26) has been arbitrarily placed where the thickness of the system is less than 100 ft and where the clastic rocks interbedded with the limestone make up more than 50 percent of the rock column between the uppermost and lowermost limestone beds that can be shown to be connected downdip. To the north and west of the line shown as the approximate updip limit of the aquifer system, thin beds, lenses, and stringers of limestone may be either connected to the main limestone body or isolated from it because of postdepositional erosion. Although these thin beds and outliers locally yield water in small to moderate amounts, they are not considered in this report to be part of the Floridan aquifer system.

The Floridan aquifer system is known to extend offshore from Georgia (McCollum and Herrick, 1964) and peninsular Florida (Rosenau and others, 1977; Schlee, 1977; Johnston and others, 1982). Because offshore geologic and hydrologic data are sparse, however, the aquifer system is not mapped offshore in this report. The Floridan contains fresh to brackish water in some offshore areas (Johnston and others, 1982), but sparse data on water quality mandate mapping of the aquifer system's freshwater-saltwater interface by indirect methods (Bush and Johnston, 1985; Sprinkle, 1985).

In part of the mapped area in South Carolina, the Upper Floridan aquifer has passed by facies change into low-permeability clastic rocks, and only the Lower Floridan aquifer is present. The effect is that of a pinchout of the Upper Floridan. The approximate area of facies change within the Upper Floridan is shown on plate 26 by a dashed northwest-trending line whose location is based on widely scattered well control. Contours to the northeast of the line represent the top of a middle confining unit that is underlain by the Lower Floridan aquifer at an altitude several hundred feet lower. Other water-bearing limestone units in South Carolina are located northeast of the area mapped in this report, but they are either hydraulically separate from the Floridan aquifer system or their permeability is too low to warrant including them in the system.

A series of faults in southwestern Alabama shown on plate 26 marks the updip limit of the aquifer system. These arcuate faults, which are part of the Gilbertown-Pickens-Pollard fault zone, bound a series of grabens. Movement along these faults has juxtaposed low-permeability clastic rocks within the grabens opposite the permeable limestone that comprises the aquifer system. The north-trending, sinuous, fault-bounded feature in Washington and Mobile Counties, Ala., is the Mobile Graben (Murray, 1961). Thin limestone beds within this graben have been downdropped and isolated from the main body of limestone. Farther westward, in southeastern Mississippi, the Floridan aquifer system passes by facies change into clastic rocks. The aquifer system is not mapped in Mississippi because it is insignificant there. Well data offshore from Mobile Bay, Ala., show that the Floridan is absent (again due to facies change) about 60 mi offshore.

CONFIGURATION AND CHARACTER OF TOP

Where the carbonate rocks that are included in the Floridan aquifer system crop out, their extent has been mapped in detail (Bennison, 1975; Copeland, 1968; Georgia Geological Survey, 1976; Vernon and Puri, 1965). The configuration of the surface of the aquifer system and the extent of the different rock units comprising its top are mapped in this report on the basis of the well control shown on plate 26, which is modified from a similar map by Miller (1982a). Detailed contouring in areas of sparse well control is based on data and maps found in published reports. The altitude of the top of the aquifer system may differ locally from the altitudes shown on plate 26 because local irregularities that have been produced by erosion or solution of the limestone may be present on the system's surface.

Plate 26 shows many localized topographic highs and lows on the aquifer system's surface in and adjacent to outcrop areas. These small features result from a combination of topography that developed when the limestone was exposed to subaerial erosion and karst topography that developed by subsurface solution of the limestone either while it was exposed or while it was buried at a shallow depth. If a smaller contour interval had been used on plate 26, many more sinkholes, solution valleys, and other types of karst features would be evident. The purpose of plate 26, however, is to show the regional configuration of the top of the Floridan aquifer system. Many of the references listed in this report contain maps that show the local topography of the aquifer system's surface in greater detail.

Because high permeability is the major criterion used in this report to delineate the top of the Floridan aquifer system, plate 26 differs locally from previously published maps (Vernon, 1973; Kwader and Schmidt, 1978; Buono and Rutledge, 1979; Knapp, 1979; Scott and Hajishafie, 1980) that show the configuration of either the top of vertically continuous limestone or the top of a specific geologic unit without regard to the permeability of the rock. In this report, any low-permeability rocks at the top of the carbonate sequence are excluded from the aquifer system. Within any of the areas where a given time-stratigraphic unit is mapped as the top of the aquifer, one- or two-well anomalies may occur if the particular time-stratigraphic unit is of low permeability throughout. Such isolated anomalies do not affect the general (regional) definition and configuration of the aquifer system and thus are not shown on plate 26.

The top of the aquifer system in most places is comprised of rocks of either Oligocene age (Suwannee Limestone or equivalent) or late Eocene age (Ocala Limestone or equivalent). Rocks of Oligocene age are thought to have once covered the entire area because (1) isolated erosional remnants of Oligocene strata are preserved as outliers surrounded by upper Eocene (Ocala) limestone and (2) a major marine transgression took place in the central and eastern Gulf Coastal Plain during Oligocene time, possibly related to a global rise in sea level (Vail and others, 1977). Post-Oligocene erosion, however, has stripped the Suwannee Limestone and equivalent strata from much of the mapped area, and left upper Eocene rocks widely exposed in outcrop and subcrop. Small patches of middle Eocene rocks that comprise the top of the aquifer system in central and southern peninsular Florida have been likewise exposed by erosion and protrude through a thin veneer of late Eocene strata because the younger rocks that once covered them have been stripped away. The area from which Oligocene rocks have been removed largely coincides with the axis and flanks of the Peninsular arch, and their absence is probably due to a slight rejuvenation or upwarp of this arch. Smaller structural features, such as some of the faults in peninsular Florida, have provided sufficient relief for younger rocks to be stripped and for older sediments to be exposed on the upthrown sides of the faults. By contrast, Oligocene outliers in southeastern Alabama (pl. 26) are not related to structure but reflect present-day topography and erosion.

Throughout most of Georgia and in north-central Florida, all rocks of Oligocene age are highly permeable and are included in the Floridan aquifer system. Accordingly, in these areas, the top of Oligocene strata coincides with the top of the aquifer system. In parts of southern Alabama, panhandle Florida, and the southern part of the Florida peninsula, the upper part of the Oligocene section consists of either low-permeability (commonly micritic) limestone or clastic rocks or both and is therefore not included in the aquifer system. In these places, then, the top of the system lies within rocks of Oligocene age rather than at their top.

Rocks of late Eocene age (Ocala Limestone) are present throughout most of the study area, are highly permeable practically everywhere, and comprise the top of the aquifer system over much of its extent (pl. 26). Upper Eocene rocks are excluded from the system only in South Carolina, where they are highly argillaceous and grade into part of the Cooper Formation, and very locally in southern Florida, where all or part of the Ocala Limestone is micritic and its permeability is accordingly low. With these exceptions, where upper Eocene rocks are present, they yield large quantities of water everywhere. In extreme western panhandle Florida, low-permeability rocks occur in the lower part of the upper Eocene section because upper Eocene limestone there passes into clastic rocks through facies change.

There are a few localities in peninsular Florida where both Oligocene and upper Eocene rocks are absent (pl. 26). In these places, middle Eocene rocks (Avon Park Formation) comprise the top of the Floridan aquifer system. Like upper Eocene rocks, the upper part of the middle Eocene section is generally highly permeable, except in updip areas where there is a transition of middle Eocene limestone into clastic sediments. In much of South Carolina, a thin unit of limestone that lies within the middle Eocene (part of the Santee Limestone) comprises the entire permeable part of the aquifer system; here, younger strata are either clastics or low-permeability carbonates or both. The top of the middle confining unit is mapped here as the top of the aquifer system.

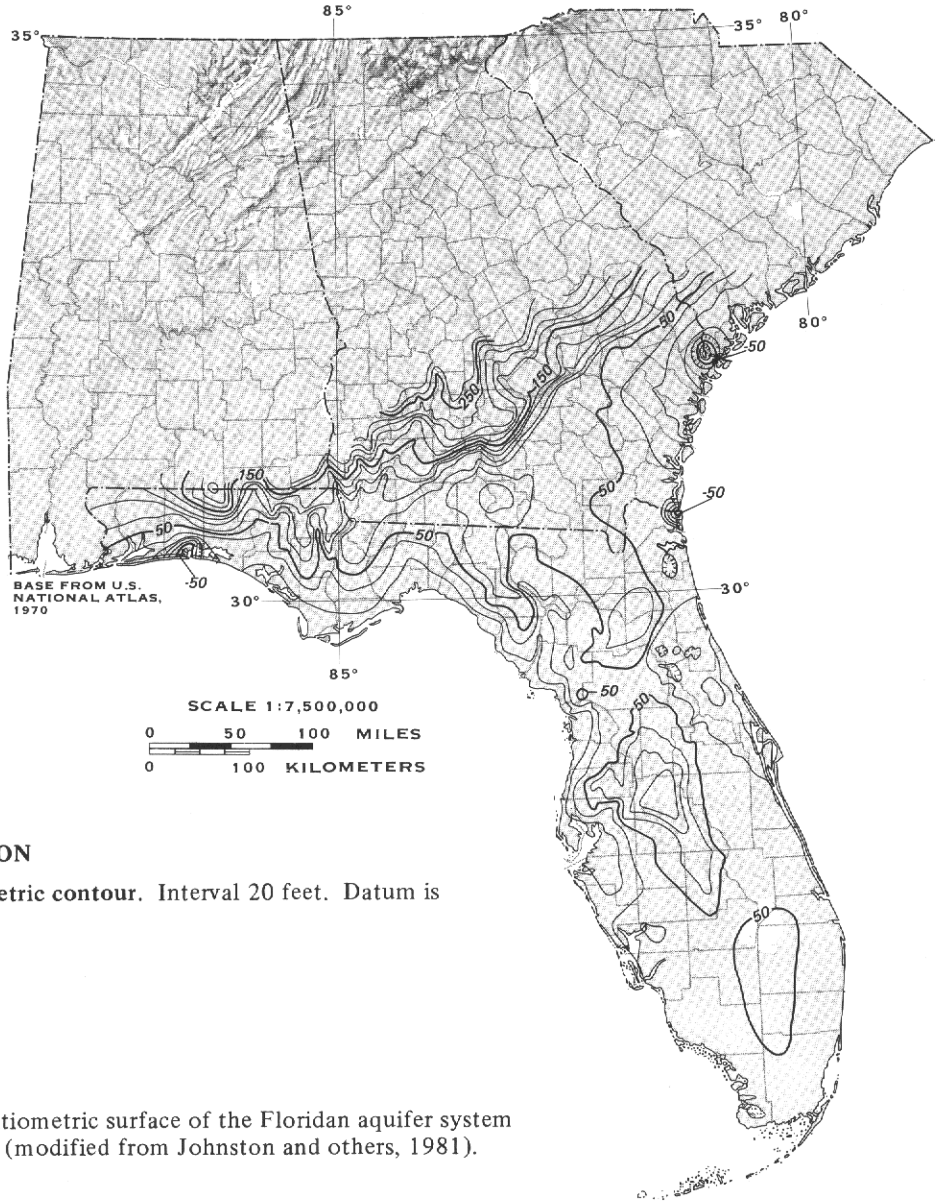
Rocks of early Miocene age (Tampa Limestone and its equivalents) mark the top of the aquifer system in a small area along the central part of peninsular Florida's Gulf Coast and in a larger area in eastern panhandle Florida. Although the area over which lower Miocene rocks are present is considerably wider than that mapped on plate 26, only within the mapped area are they permeable enough to be included as part of the Floridan aquifer system.

Even though plate 26 is a composite of several time-stratigraphic levels, major geologic structures are shown as large-scale features on the map and are generally expressed as a series of broad high and low areas that interrupt the steady, gentle seaward slope of the aquifer system's top. For example, the Southeast Georgia embayment is shown as an east-trending negative area centered near Brunswick, Ga.; the low area in and near Gulf County, Fla., is part of the Southwest Georgia or Apalachicola embayment; the low areas in central Lee County and northern Monroe County, Fla., are arms of the South Florida basin. The influence of the Gulf Coast geosyncline is reflected as a steep, steady gulfward slope of the top of the aquifer system in extreme western panhandle Florida and in southern Alabama.

Parallel to northern peninsular Florida's western coast and extending for a short distance into southwestern Georgia is an elongate, broad, northwest-trending high area. This high, known in the literature as the Ocala uplift, has been thought to represent an arch or an anticline, partly because, like a classic anticline, older rocks are exposed near its "axis." This "axis," although clearly shown on a map of the surface of rocks of late Eocene age (pl. 8), is not present on a map of the top of rocks of middle Eocene age (pl. 6), nor does it occur on maps of older geologic units or on a map of the base of the aquifer system (pl. 33). This author agrees with Winston (1976) that the Ocala uplift is not a structural uplift in the classic sense. The "uplift" may reflect post-Eocene tilting of the Florida peninsula, as Winston proposed, or it may be merely the result of differential compaction of soft carbonate rocks over an irregular depositional surface.

A subtle positive feature in extreme southeastern Alabama and southwestern Georgia (pl. 26) is in the same location as the feature that has been called the Chattahoochee arch or anticline by some authors. This positive area is not shown on maps of the tops or thicknesses of the several time-stratigraphic units that comprise the aquifer system (pls. 3-11), nor is it present on a map of the base of the system (pl. 33). Patterson and Herrick (1971), after reviewing all published evidence, concluded that the Chattahoochee anticline was hypothetical rather than real. This author agrees that there is no evidence for a structural feature where this "anticline" is supposedly located and concludes that the apparent "structure" is in fact an erosional feature, perhaps exaggerated by a change in the strike of the outcropping coastal plain rocks from a northeastern alinement along the Atlantic Coastal Plain to an east-west alinement along the Gulf Coastal Plain.

In addition to the faults in Alabama that form part of the updip limit of the Floridan aquifer system, several small faults concentrated in eastern peninsular Florida and central Georgia are shown on plate 26. The locations of the faults shown in Florida were taken from the literature and changed slightly where it was necessary to conform with well data. Most of the Florida faults are downthrown on the oceanward side, and all appear to be normal or gravity faults. All of the faults shown displace rocks of late Eocene age, and at least one, in southern Florida, which extends from Indian River County southeast to Martin County, is post-Oligocene in age. From Volusia County southward, younger rocks have commonly been eroded from the upthrown sides of these faults, and older strata have thus been exposed in subcrop. None of the Florida faults mapped has a major effect on the flow system of the Floridan, as a comparison of the potentiometric surface (fig. 10) with the fault locations on plate 26 shows. All of the faults are of small displace-



EXPLANATION

—150— **Potentiometric contour.** Interval 20 feet. Datum is sea level

Figure 10. Potentiometric surface of the Floridan aquifer system in May, 1980. (modified from Johnston and others, 1981).

ment, and where they occur, the upper few hundred feet of the aquifer system is highly permeable, regardless of which time-stratigraphic unit it lies within. Fault movement has accordingly juxtaposed rocks of similar permeability and has resulted in only a slight difference in the thickness of the aquifer system. The ground-water flow system is accordingly unaffected.

When the small northeast-trending grabens shown in central Georgia on plate 26 are taken together, they represent a negative feature called by Herrick and Vorhis (1963) the "Gulf Trough of Georgia," a name subsequently shortened to "Gulf Trough" (Hendry and Sproul, 1966). Herrick and Vorhis did not postulate faulting as the cause of the Gulf Trough. Gelbaum (1978) and Gelbaum and Howell (1982), however, indicated that faulting could have formed many if not all of the small elongate basins that constitute the Gulf Trough, an interpretation with which this author agrees. In contrast to the Florida faults discussed above, the faults bounding the Gulf Trough grabens show considerable vertical displacement. The graben system affects the permeability characteristics, the thickness, and the configuration of the top of the Floridan aquifer system, and is also evident on maps of the tops and thicknesses of stratigraphic units ranging in age from middle Eocene to middle Miocene. Limestone units that are part of the aquifer system are less permeable within the Gulf Trough those than on either side (Gelbaum and Howell, 1982), and the system is thin within the trough (pl. 27).

The Gulf Trough coincides with a bunching of contours on a map of the potentiometric surface of the Floridan aquifer system (fig. 10). Such a steep hydraulic gradient can be caused by a decrease in transmissivity. Very low specific capacities for Floridan wells within the trough suggest that the aquifer system is less transmissive there; ground-water modeling tends to confirm this suggestion. The grabens that comprise the trough are bounded by steeply dipping normal faults. Displacement along these faults has downdropped low-permeability Miocene clastic sediments within the grabens opposite the permeable limestone that borders the grabens on both sides (pl. 26). The result is a damming effect at the trough on the generally southeast-flowing ground water within the Floridan. The combination of low-transmissivity limestones in the grabens and the retardation of flow by the juxtaposition of a thick sequence of low-permeability clastic rocks opposite the limestone accounts for the steep hydraulic gradients that exist in the aquifer system in the Gulf Trough area.

THICKNESS

The Floridan aquifer system generally thickens seaward from a thin edge near its approximate updip limit. Plate 27, updated and modified from a map by Miller (1982b), shows the thickness of the entire aquifer system, including the Upper and Lower Floridan aquifers and the middle confining unit that separates them. The thickness mapped includes all strata between the top of the highest vertically continuous permeable limestone sequence (top of the aquifer system) and the top of the low-permeability clastic or evaporitic rocks that form the base of the system. Well point data have been used primarily to construct the thickness map and have been supplemented in areas of sparse well control by thickness estimates obtained by subtracting contoured elevations of the top and base of the aquifer system (pls. 26, 33). Thicknesses may vary locally from those shown, especially where erosion or karst topography has created considerable relief on the aquifer system's surface.

The Floridan aquifer system is composed of all or parts of several different formations and (or) time-stratigraphic units in different combinations at different places. Plate 27 therefore represents a composite thickness that may encompass only a part of a single formation in updip areas or may include several time-stratigraphic units downdip. Because the aquifer system is defined primarily by the occurrence of permeable carbonate rocks, plate 27 cannot be interpreted in exactly the same way as an ordinary isopachous map. Some of the thickening and thinning trends shown on the map are, however, related to depositional conditions and geologic structure. Some of the large-scale structures in the mapped area have maintained their relative positive or negative character over long periods of geologic time. For this reason, and because movement on these features kept pace with depositional rates, basin conditions remained very much the same, and thick sequences of carbonate rocks of similar lithology were deposited. The major structural features in the study area shown on plate 27 are areas of major thickening or thinning of the aquifer system.

The Floridan aquifer system is typically composed of platform carbonate rocks that were deposited in warm, shallow water as limestones of various textures and were subsequently dolomitized in varying degrees. This platform carbonate sequence is best developed to the south and east of the 1,000-ft thickness contour shown on plate 27. North and west of this contour, the carbonate rocks interfinger with clastic sediments in an area that represents spillover of carbonate deposition onto a foreland basin that was receiving clastic sediments from a landmass to the north and west. In upbasin areas, this dual source of sediment supply resulted in complex interbedding and interfingering of clastic and carbonate rocks. As the carbonate rocks thin toward the updip limit of the aquifer, the amount of clastic material admixed with them increases. These factors account for the lower permeability and transmissivity (Bush and Johnston, 1985) of the aquifer system in an upbasin direction.

In north-central peninsular Florida (pl. 27), the limestone units that comprise the aquifer system thin over the crest and flanks of the Peninsular arch. The great thicknesses of carbonate rocks in the eastern panhandle of Florida and in southeastern Georgia have accumulated in the Southwest and Southeast Georgia embayments, respectively. The thick area in Manatee and Sarasota Counties, Fla., is thought to be part of the South Florida basin. The thick area in southern Martin County, Fla., does not correlate with any known structural feature; the aquifer system is thick simply because the anhydrite beds that mark its base in southern Florida are exceptionally deep. The aquifer system does not thicken greatly in a gulfward direction in western panhandle Florida and southern Alabama, as one might expect. The supply of clastic sediments from the north and west was great enough here to preclude the deposition of limestone throughout most of that the time the aquifer system was being formed.

A small graben system in central Georgia cuts through the entire thickness of the aquifer system (section B-B', pl. 16), and was apparently active during as well as after deposition of the limestone that makes up the system. The series of small grabens shown on plate 27 comprises the Gulf Trough discussed earlier.

For the most part, there are more clastic rocks and low-permeability limestone within these grabens than there are to the northwest and southeast of the normal or gravity faults that bound them. Because of the greater amount of clastic material in the grabens, the aquifer system is much thinner within them. For example, near Moultrie in Colquitt County, Ga., the aquifer system is less than 200 ft thick within one of the grabens but is more than 500 ft thick to the northwest, in an upbasin direction where the aquifer system would normally be expected to be thinner.

Movement along the faults of the graben system has downdropped low-permeability clastic rocks within the grabens opposite permeable limestone on either side of them. This juxtaposition has restricted the flow of ground water across the grabens and down the hydraulic gradient from them. Throughout the shaded area shown on plate 27 (southeast of the graben system and extending from Gadsden County, Fla., northeast to Berrien County, Ga.), the aquifer system is thin and consists of only a few hundred feet of permeable limestone underlain by gypsiferous limestone. The ground-water flow across this area, restricted by the grabens to the northwest, has not been sufficient to completely dissolve the gypsum contained in the limestone.

In southwestern Alabama, the arcuate faults shown on plate 27, like those in central Georgia, bound a series of grabens. Gulfward of these grabens (except in southern Mobile County, Ala.), there is very little limestone; thick sequences of clastic rocks in the grabens and seaward of them are the Floridan aquifer system's equivalent.

An oval-shaped northeast-trending thick pod of limestone in Clinch and Echols Counties, Ga., possibly represents the Suwannee Strait, a poorly understood channel-like feature that was once thought to separate predominantly clastic rocks to the northwest from predominantly carbonate rocks to the southeast. Because the feature as mapped on plate 27, is closed to the northeast and southwest, it is obviously not a channel. Its exact origin is not known, however.

There are several local, flat, shelflike features shown on plate 27 in southern Florida. The most prominent are just south of Miami in Dade County, north of Fort Pierce in St. Lucie County, and in Lee County. These shelflike areas are apparent, not real, and are the result of differences in elevation of the evaporite deposits that comprise the base of the aquifer system in southern Florida. These low-permeability evaporites occur at different altitudes in different wells because they interfinger with carbonate rocks as a series of discrete large lenses. Regionally, the lenses are mapped as if they were a single horizon, and their interfingering nature creates the illusion of irregular topography. The anhydrite that represents the base of the Floridan aquifer system is high under all these shelflike areas, and the aquifer system above these high spots is accordingly thin.

MAJOR HYDROLOGIC UNITS WITHIN THE FLORIDAN AQUIFER SYSTEM

The Floridan aquifer system is extremely complex because (1) the rocks that comprise it were originally laid down in highly variable depositional environments, and their texture and mineralogy accordingly vary considerably; (2) diagenesis has produced much change in the original sediments in places, and (3) large- to small-scale karst features are developed at several levels in the aquifer system owing to modern and ancient dissolution of the limestone. These factors, alone or in combination, create much local variability in the aquifer system's lithology and permeability characteristics. It is necessary, therefore, to generalize greatly both the geology and the hydraulic parameters of the aquifer system to present a regional view of each. Also, to simulate regional ground-water flow with a digital computer model, the complexities of local variations in geology and hydraulic properties must be simplified. Regionally, as mentioned earlier (section "Floridan Aquifer System"), the Floridan aquifer system generally consists of an Upper and a Lower Floridan aquifer separated by a middle confining unit. Neither the separate aquifers nor the middle confining unit is everywhere the same thickness or age or necessarily consists of the same type of rock. In places, no middle confining unit exists, and the entire aquifer system is more or less permeable. In other places, such as southern Florida, most of the aquifer system consists of low-permeability rocks separating thin zones of high permeability. Within regionally extensive aquifers or confining units, there may be from one to several local zones of contrasting permeability (see, for example, section E-E', pl. 21); these local zones, however, do not usually affect the overall character of the given aquifer or confining unit, even though a given zone may locally have an important hydraulic influence.

The upper major permeable zone of the aquifer system, herein called the Upper Floridan aquifer, yields large volumes of water nearly everywhere, and the water is usually of good chemical quality. As a result, few water-supply wells penetrate the aquifer system's middle confining unit and the Lower Floridan aquifer, which lie at considerable depth. The hydrologic character of these deeper parts of the aquifer system is therefore known from only a few scattered deep wells, most of which were constructed to test their